SURFACE TREATMENTS TO IMPROVE THE WEAR RESISTANCE OF TYPE 304 STAINLESS STEEL IN WATER

by

O. Ogunlade and R. D. Watson

SYNOPSIS

Various surface treatments were applied to 304 stainless steel journals in an attempt to improve their wear resistance. The treatments consisted of one or more of the following; shot-blasting with Glas-shot or chilled-iron-shot, heating in air, in argon containing air or in vacuum. The treated journals were tested against Waukesha 88 bearings at loads of 20, 40 and 60 lb and speeds of 40 and 180 rev/min, in 80°F pH 7 water. Representative specimens of the various treatments were metallographically examined to determine the nature of the surface.

In general, treated journals had much better wear resistance than untreated journals. The improvement was believed to be due mainly to surface oxidation.

The best surface treatment consisted of Glas-shot blasting the surface followed by heating in air at 800°C for 21 h.

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1. INTRODUCTION

Because of its excellent corrosion resistance[4] 304 stainless steel is extensively used in mechanisms operating in water at temperatures up to 500°F (or even higher). Two serious drawbacks to the use of 304 stainless steel are its poor wear resistance and its tendency to gall and seize when very little clearance is provided. Regardless of these drawbacks it is often specified and quite often galling and seizure occur. A method which eliminates this tendency to gall and seize but does not reduce the corrosion resistance or other desirable properties would be an asset.

An earlier investigation[2] showed that an oxide layer on 304 stainless steel improved its wear resistance, but lack of a method to produce the oxide layer consistently prevented the use of the process.

Since the earlier work, several new methods have been tried. One of these, surface shot-blasting followed by heating, appeared to be an improvement on the original method. In order to assess this new method several specimens were prepared and wear-tested to determine the wear resistance of the coating. The results were reasonably encouraging. A metallographic examination of the surface revealed a very thin oxide layer at the surface and a relatively thick layer just below the surface where heavy carbide precipitation had occurred along the slip planes within the grains and along the grain boundaries. Although we had originally assumed that the improved wear resistance was due only to the thin oxide layer on the surface there was now reason to believe that carbide precipitation might also be a factor in improved wear resistance.

The current program was therefore undertaken to determine what actually improved the wear resistance. This report describes the work done and the results obtained. One of the outcomes of the program was a suitable method of consistently forming a uniform oxide coating on 304 stainless steel.

2. PRINCIPLE OF METHOD

In order to determine whether carbide precipitation, surface oxidation or their combination was responsible for the increased wear resistance of 304 stainless steel, it was necessary to determine the effect of the following on the wear resistance:

(a) Shot blasting alone

(b) Shot blasting + heating in vacuum

(c) Shot blasting + heating in an atmosphere containing air

(d) Heating in air only.

A number of 304 stainless steel journals were given the various treatments shown in Table 1. The treated journals were wear-tested in water against Waukesha 88 bearings. The results of each test were compared with one another and with the results of tests on untreated journals, to determine the effect of the various parameters.

Samples of the differently treated surfaces were metallographically examined for structural differences.

The results of the wear tests and the metallographic work were used as the basis for determining what actually improved the wear resistance.

3. JOURNAL SURFACE TREATMENTS

Type 304 stainless steel journals were machined to a nominal size of 3/4 in. OD × 1/2 in. ID × 1 in. long, ground to 10-30 μin. AA, thoroughly degreased and cleaned, then given one of the treatments shown in Table 1. The shot blasting was performed with conventional grit blasting equipment using air at 100 lbf/in^2 gauge.

4. TEST EQUIPMENT AND CONDITIONS

The equipment used for wear testing in this program has been adequately described previously[3, 5]. Figure 1 shows a cross-section of the test head with journal and bearing in position. Figure 2 shows the test head assembly including the test water tank, and the water feed and return pipes.

Tests were run at loads of 20, 40 and 60 lb and speeds of 40 and 180 rev/min in 80°F pH 7 water.

5. TEST PROCEDURE

A standard cleaning procedure, which gave reproducible surface cleanliness, was followed to clean all specimens[5]. After cleaning, each specimen was carefully weighed and inspected. The journal OD was measured before cleaning and the bearing ID after installation in the holder.

The test specimens were installed in position as shown in Figure 1, the load was applied and the rig was operated at the desired speed. The friction torque was measured at least 3 times (more often when the run lasted more than a day) during a test run by positioning the rider on the load arm (see Figure 2) so that it balanced the friction torque of the test bearing.

Each test consisted of at least three test runs for a total sliding distance of two million inches or greater. After each test run, the specimens were cleaned, weighed, and inspected.

Wear was measured as weight loss. The coefficient of friction, for each test run, was calculated using the average of the friction torques recorded during the test run. Table 3 is a typical test data sheet.

Curves showing the relationship between total wear and sliding distance were plotted for each test. Specific wear[3, 4] was calculated for each specimen from the weight loss measurements.

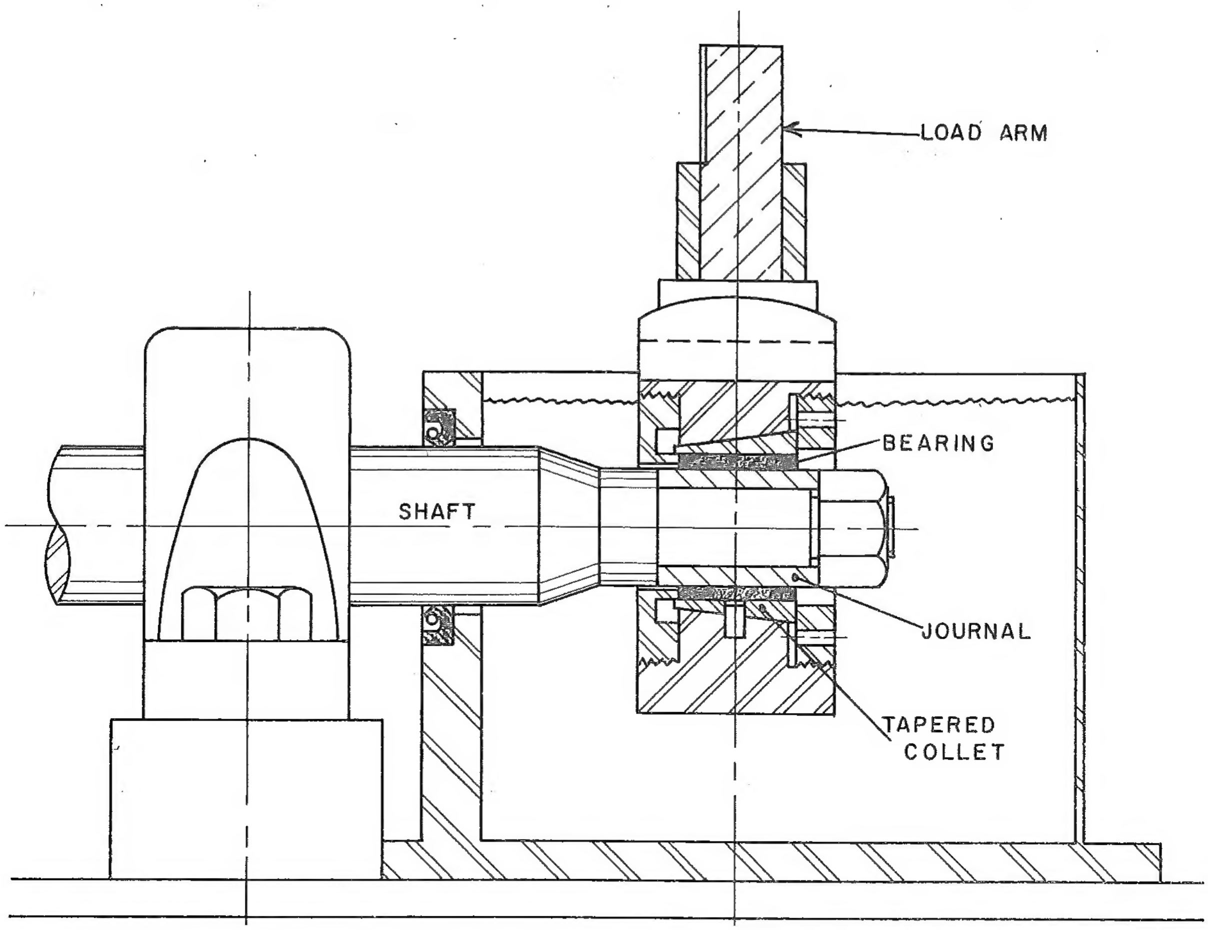


FIGURE 1: Cross-Section of Test Head Showing Journal and Bearing Specimens in Test Rig

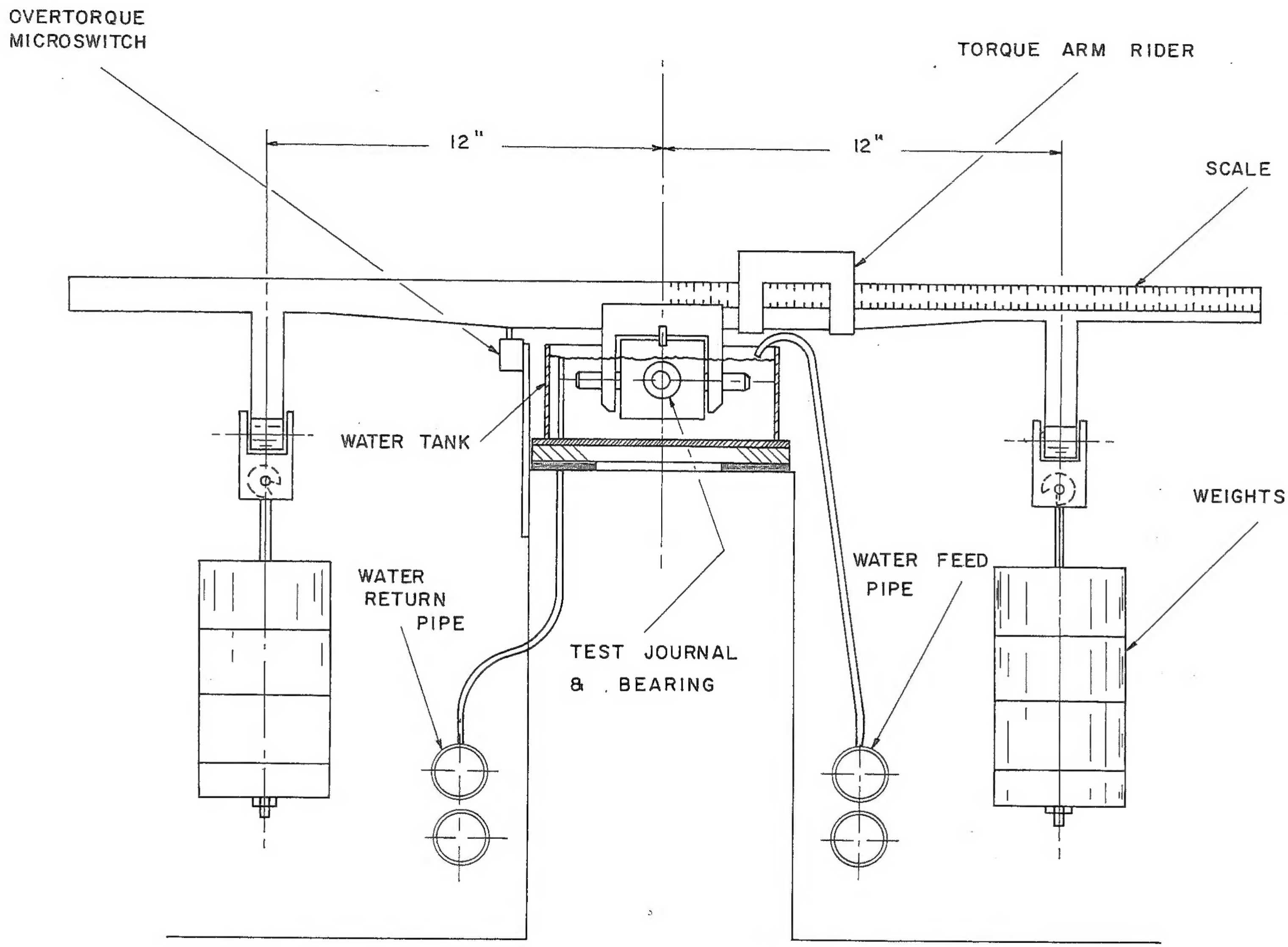


FIGURE 2: Diagram of Low Temperature Bearing Test Head

6. FRICTION AND WEAR TEST RESULTS

Table 1 summarizes the test results which have been arranged according to the different surface treatments. Table 2 gives the results of wear tests on untreated journals. Graphs of total wear versus sliding distance for treated and untreated journals under various conditions of load and speed are shown in Figures 3 to 6.

The results in Tables 1 and 2 and Figures 3 to 6, show that the specific wear for all tests on treated specimens is considerably less than that of comparable tests on untreated specimens.

Treatment b-6 in Table 1, consisting of Glas-shot blasting followed by 21 h heating in air at 800°C gave consistently good results at the 3 different loads. The specific wear was quite low, the surface finish improved (high value of coefficient of polish) and the coefficient of friction decreased during the test (a low friction index). Treatments consisting of Glas-shot blasting followed by a 4 h heating period gave good results at loads of 20 and 40 lb but not at 60 lb. Treatment d (see Table 1) consisting of Glas-shot blasting followed by vacuum heating was not nearly as effective as Glas-shot blasting followed by heating in air. By itself, Glas-shot blasting was a very unsatisfactory surface treatment (see Table 1, treatment e). The treatment consisting of chilled-iron-shot blasting followed by a 4 h heating period was better than treatment d but not as good as b-6.

7. METALLOGRAPHIC EXAMINATION

The surface coating and sub-surface structure of representative samples of the different treatments were metallographically examined.

The surface coatings were very thin (maximum 0.0002 in.) and irregular. Most of the heated "as ground" specimens had no coating at all. The Glas-shot blasted specimen heated for 21 h had the best coating (Figure 7).

Figures 8 to 12 show the sub-surface structures of specimens having the following treatments:

(i) ground and heated at 800°C in air
(ii) Glas-shot blasted and heated at 800°C in air
(iii) chilled-iron-shot blasted and heated at 800°C in air
(iv) Glas-shot blasted and heated at 800°C in vacuum
(v) Glas-shot blasted only.

When the surface of a 304 stainless steel specimen is shot-blasted it becomes work-hardened at the surface and to some depth beneath the surface. Surface grinding also produces work-hardening but to a lesser degree. During work hardening slip lines form within the crystals. In Figures 8 to 11 the slip lines (heavy cross-hatching) are sharply defined by the carbide precipitate which resulted from heating within the sensitization range (800° to 1600°F). The heavy black areas near the surface in these figures are the result of a super abundance of slip lines with carbide precipitation along them. In Figure 11, the slip lines (light cross-hatching) are not sharply defined because the specimen was not heat treated.

8. DISCUSSION OF RESULTS

There was a large variation in the effect of the different surface treatments on the wear resistance of the 304 stainless steel versus Waukesha 88 combination. The following is a list of the various surface treatments in order of improving wear resistance:

(i) Glas-shot blasting (no heating)
(ii) Glas-shot blasting plus vacuum heating, 2 h at 800°C
(iii) Chilled-iron-shot blasting plus heating in an atmosphere containing air, 4 h at 800°C
(iv) Grinding plus heating in air, 2 to 4 h at 800°C
(v) Glas-shot blasting plus heating in an atmosphere containing air, 4 h at 800°C
(vi) Glas-shot blasting plus heating in air, 21 h at 800°C.

Glas-shot blasting alone (i) does not improve wear resistance. In fact, the results of the wear test using this treatment were worse than no treatment at all.

Glas-shot blasting plus vacuum heating (ii) was better than Glas-shot blasting alone (i). In the vacuum heated specimen there was heavy carbide precipitation near the surface (see Figure 11) and in the unheated specimen there was none (see Figure 12). This heavy carbide precipitation layer might be responsible for the improved wear resistance.

Surface grinding plus heating in air (iii) was better than Glas-shot blasting plus vacuum heating (ii). Surface oxidation was probably responsible for the improvement.

Grinding plus heating in air (iv) was better than chilled-iron-shot blasting plus heating in air (iii). The oxide formed in both cases was about the same but the shot blasting roughened the specimens and this might account for the difference in results.

Glas-shot blasting plus heating for 4 h in air (v) was considerably better than (iv). The Glas-shot blasting appeared to promote uniform oxidation of the surface, more so than did the chilled-iron-shot blasting. The improvement in wear resistance provided by (v) was probably due to a thicker and more uniform oxide coating and not to the structure below the surface. A considerable improvement in wear resistance at 60 lb was provided by a 21 h heating period in air after Glas-shot blasting (vi). The improved wear resistance was attributed to the thicker oxide coating. A specimen heated for 48 h provided neither thicker oxide coating nor better wear resistance than (vi).

From the preceding paragraphs it would appear that most of the improvement in wear resistance is due to the oxide coating on the surface. Glas-shot blasting is helpful in that it appears to provide a surface that will oxidize consistently and uniformly.

Some improvement in wear resistance seems to result from changes in the surface and sub-surface structure which have been produced by shot blasting followed by heating at 800°C. Heavy carbide precipitation along the slip planes within the crystal could be responsible for some of this improvement.

9. CONCLUSIONS

9.1 The wear resistance of 304 stainless steel against Waukesha 88 in water can be improved over that of untreated stainless steel by any one of the following procedures:

(a) Glas-shot blasting followed by heating in air at 800°C for 21 h.

(b) Glas-shot blasting followed by heating at 800°C in an atmosphere containing air for 2 to 4 h.

(c) Heating in an atmosphere containing air at 800°C for 2 to 4 h.

(d) Chilled-iron-shot blasting followed by heating at 800°C in an atmosphere containing air for 2 to 4 h.

(e) Glas-shot blasting followed by heating in vacuum at 800°C for 4 h.

9.2 The wear resistance of Glas-shot blasted 304 stainless steel against Waukesha 88 in water was worse than untreated 304 stainless steel.

9.3 The improved wear resistance of parts treated by procedures 9.1 (a), (b), (c), and (d) is mainly due to the surface oxide layer.

9.4 The increased surface hardness, resulting from Glas-shot blasting alone, did not improve the wear resistance of 304 stainless steel.

9.5 The best method of improving the wear resistance of 304 stainless steel against Waukesha 88 in water is to Glas-shot blast the 304 stainless steel and heat in air at 800°C for 21 h. An oxide layer about 0.0002 in. thick is formed.

10. REFERENCES

(1) R.D. Watson and O. Ogunlade, "Results of Friction and Wear Tests at Chalk River", MechED-FW-10, Internal Report, July 18, 1967 (Revised June 6, 1968).

(2) R.D. Watson, "Wear and Corrosion in Water", AECL-2566, February 1966.

(3) J.T. Dunn, "Wear of Plastics in Room Temperature Water", AECL-2532, February 1966.

(4) J.T. Dunn, "Wear Rates of Metals and Oxides in 80° and 160°F High Purity Water", AECL-2602, August 1966.

(5) O. Ogunlade, "Effect of pH on the Wear Characteristics in Water of Ten Metal Combinations", AECL-2784, October 1967 .

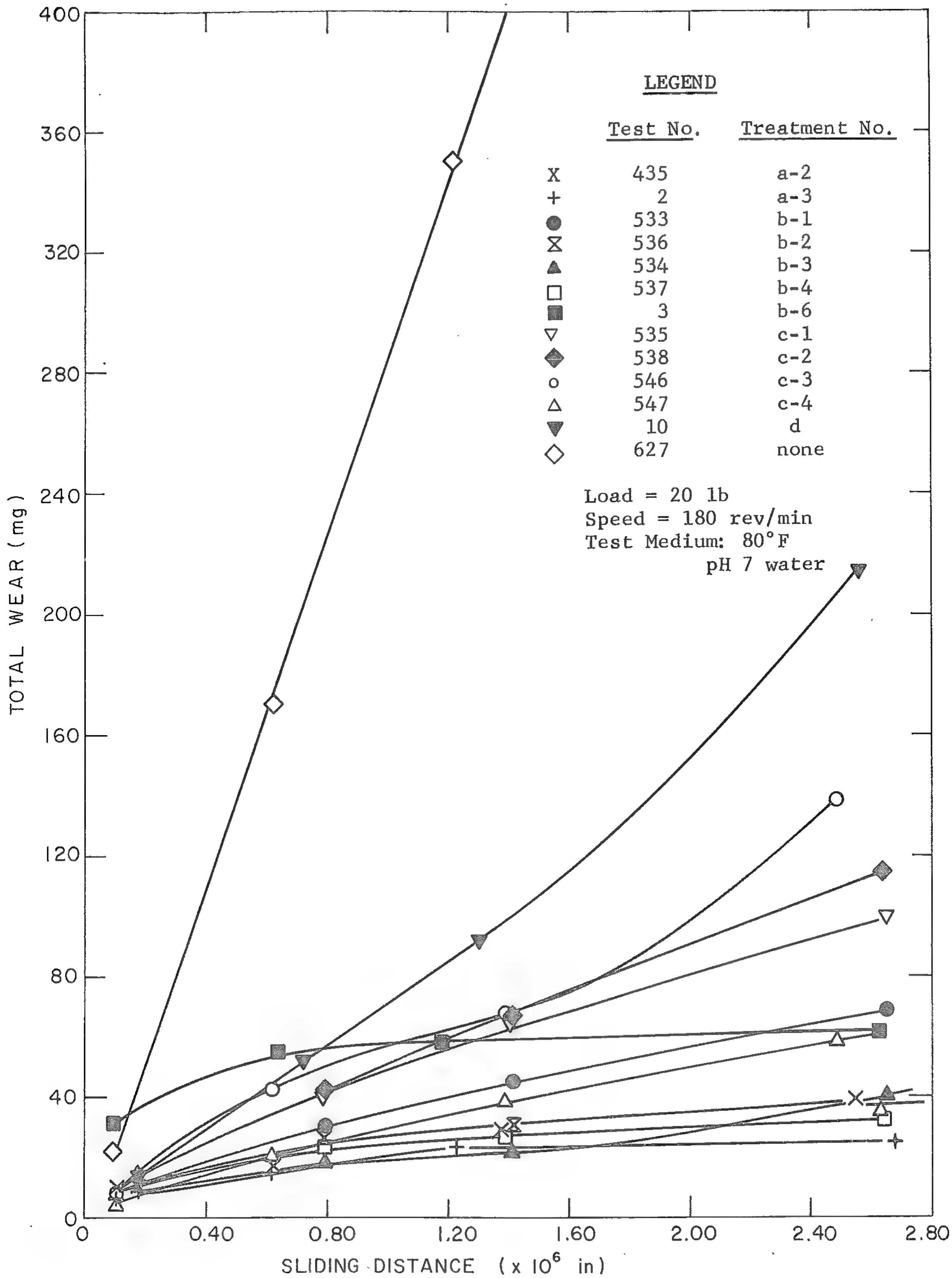


FIGURE 3: Wear Characteristics of Different Surface Treatments

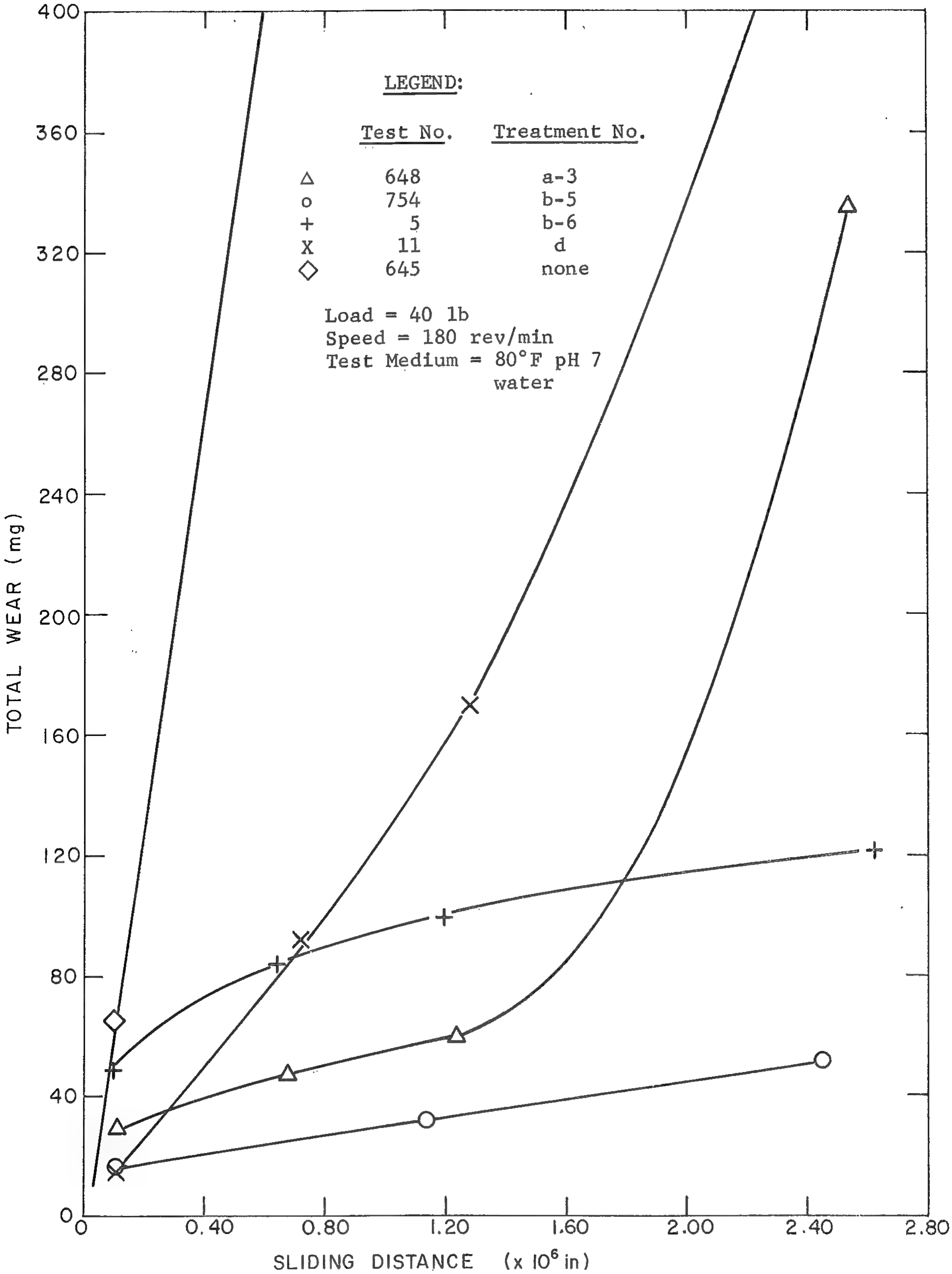


FIGURE 4: Wear Characteristics of Different Surface Treatments

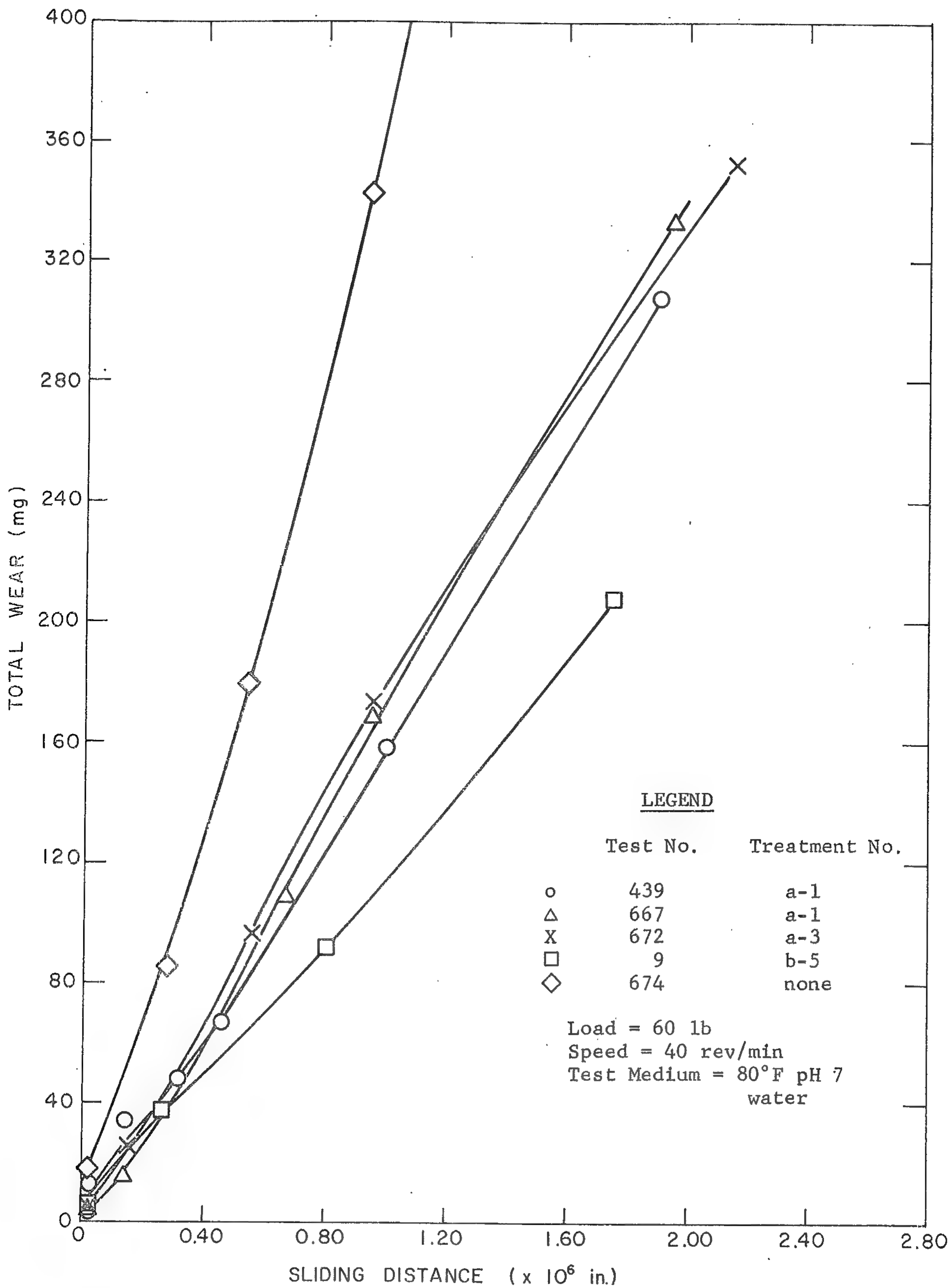


FIGURE 5: Wear Characteristics of Different Surface Treatments

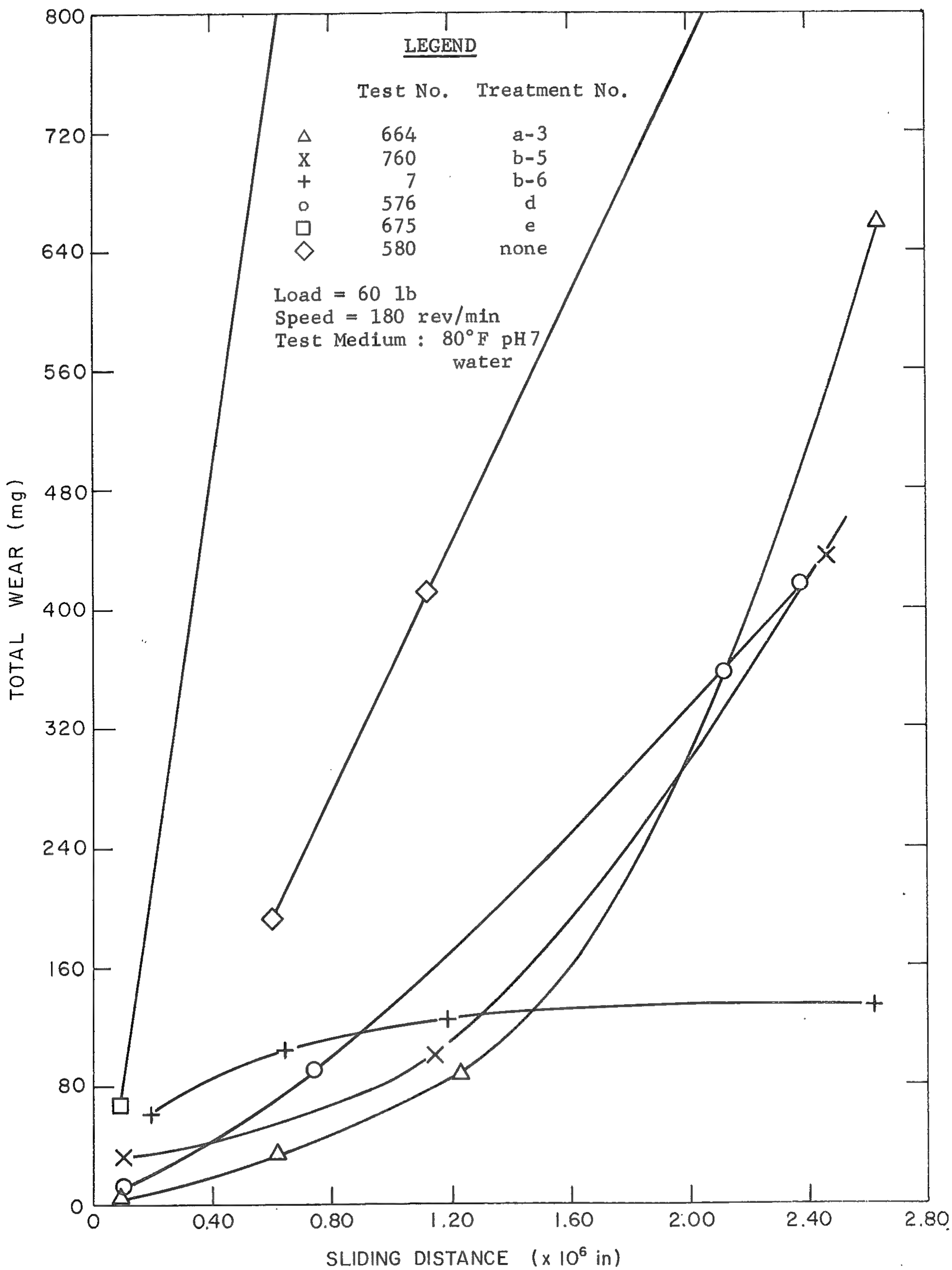
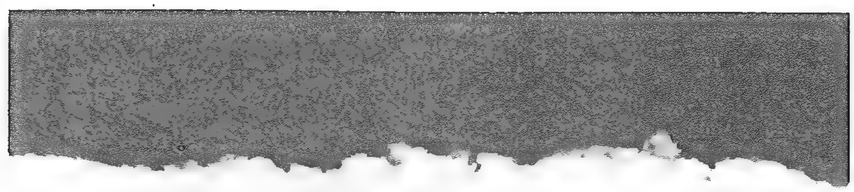
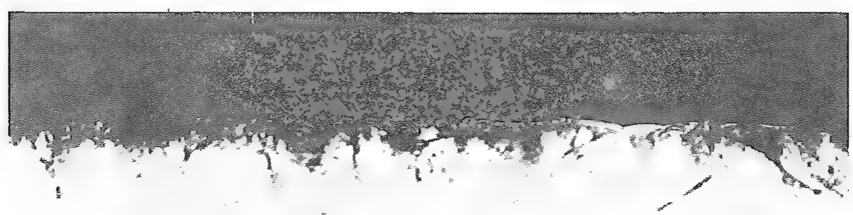


FIGURE 6: Wear Characteristics of Different Surface Treatments



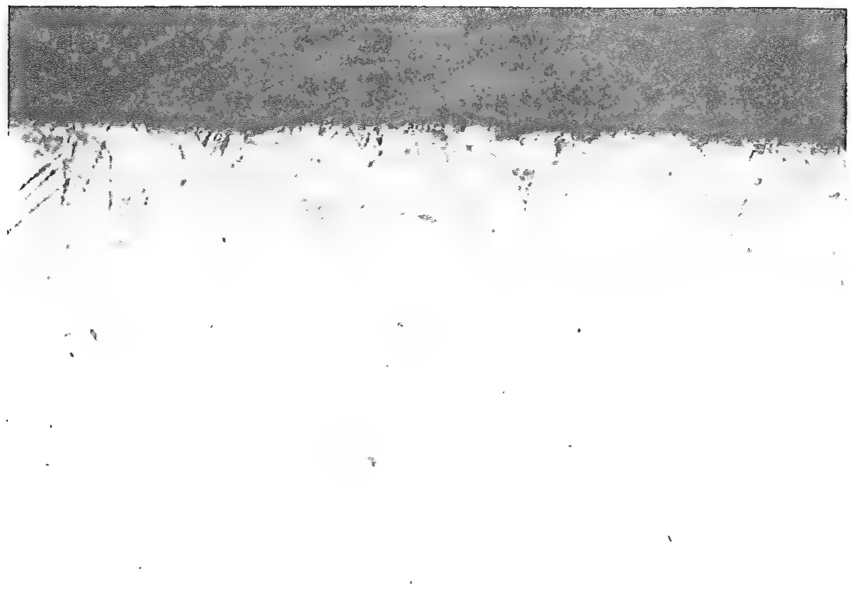
1000 X

FIGURE 7: Representative area of grey oxide layer on the OD of a 304 SS journal after heating at 800°C for 21 h. (treatment b-6)



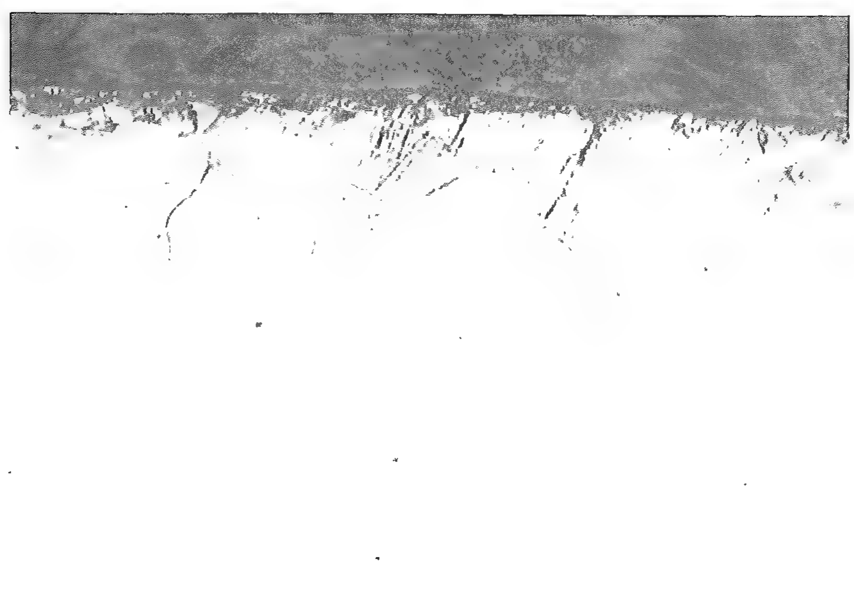
250 X

FIGURE 8: Representative area showing sub-surface structure of "as ground" 304 SS journal after heating at 800°C. Note heavy carbide precipitation along the slip lines within the grains near the surface. (treatment a-3, test 648)



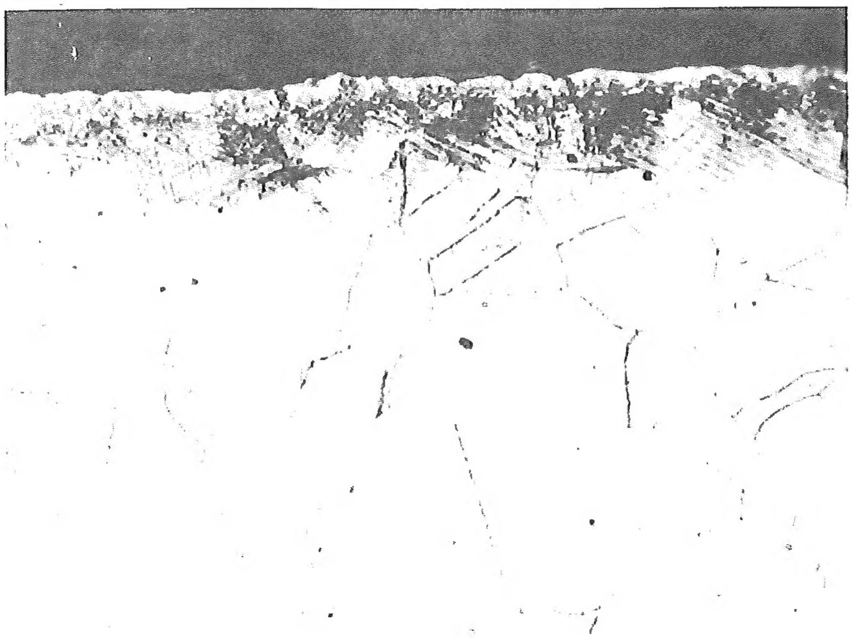
250 X

FIGURE 9: Representative area showing sub-surface structure of Glas-shot blasted 304 SS after heating at 800°C: Note carbide precipitation at surface and along slip lines within the grains (treatment b-3, test 534)



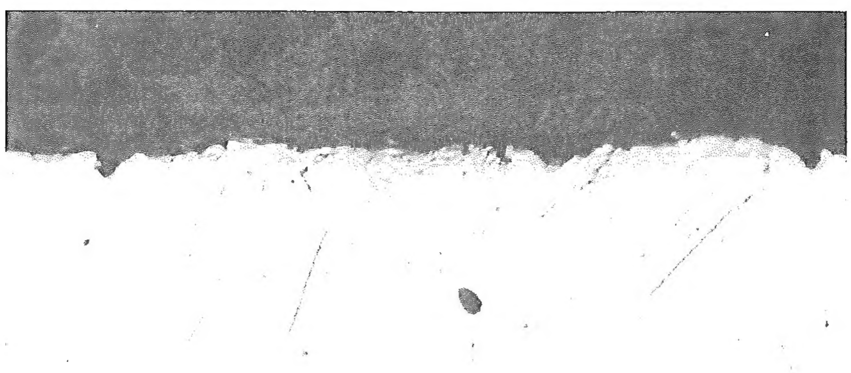
250 X

FIGURE 10: Representative area showing sub-surface structure of chilled-iron-shot blasted 304 SS journal after heating at 800°C: Note heavy carbide precipitation near surface and along slip lines within the grains (treatment c-1, test 535)



500 X

FIGURE 11: Representative area showing sub-surface structure of Glas-shot blasted, vacuum heated 304 SS journal: Note heavy carbide precipitation along the slip lines within the grains near the surface. (treatment d, test 11)



500 X

FIGURE 12: Representative area showing sub-surface structure of Glas-shot blasted 304 SS journal: Note slip lines within grains. (treatment e, test 675)

TABLE 1: Surface Preparation of 304 SS, and Test Data and Results on Surface Treated 304 SS Versus Waukesha 88

Treatment No.	Test No.	Pre-Heat Treatment: Surface Blasted With		Heat Treatment			Cooling				Test Conditions					Results				Av. Total Specific Wear Using Untreated Journals (Table 2)
		Glas-shot .0021 in. to .0041 in. diam.	Chilled Iron-shots .02 in. to .04 in. diam.	Atmosphere	Temp. °C	Time h	Water Quench	Oil Quench	Air Cooled	Furnace Cooled	Load lb.	Speed rev/min.	Temp. °F	Clearance $\times 10^{-3}$ in.	Test Length $\times 10^{6}$ in.	Total Specific Wear[1]	Journal Specific Wear[1]	Polish[2] Pol	Friction Index[3] f_I	
a-1	439			Air	800	2			*		60	40	80	9.0	2.838	20	12	0.03+	2.02	35
	667			Air	800	2			*		60	40	80	8.1	2.893	27	14	0.04+	1.54	35
a-2	435			Air	800	4		*			20	180	80	9.6	2.550	5	0.1	0.74	0.52	88
a-3	2			Air	800	4			*		20	180	80	8.6	2.680	3	0.4	1.04	0.76	88
	648			Air	800	4			*		40	180	80	8.5	2.540	22	0.1	0.15	0.22	93
	672			Air	800	4			*		60	40	80	9.0	2.150	20	12	0.01+	1.54	35
	664			Air	800	4			*		60	180	80	8.8	2.640	29	6	0.03+	1.64	45
b-1	533	*		Air	800	4	*				20	180	80	9.2	2.650	9	2	7.41	0.42	88
b-2	536	*		Air	800	4		*			20	180	80	9.6	2.640	5	0.3	4.10	0.22	88
b-3	534	*		Argon & Air	800	4		*			20	180	80	7.9	2.650	4	0.3	3.00	0.52	88
b-4	537	*		" "	800	4			*		20	180	80	2.4	2.640	4	0.04	3.80	0.71	88
b-5	754	*		Air	800	4			*		40	180	80	8.3	2.450	4	0.5	5.38	0.61	93
	9	*		Air	800	4			*		60	40	80	8.0	1.750	13	2	0.05+	1.48	35
	760	*		Air	800	4			*		60	180	80	8.4	2.450	20	4	0.11+	1.24	45
b-6	3	*		Air	800	21			*		20	180	80	7.7	2.620	8	0.1	4.25	0.39	88
	5	*		Air	800	21			*		40	180	80	8.7	2.620	8	0.01	4.75	0.26	93
	7	*		Air	800	21			*		60	180	80	8.3	2.620	6	0.1	7.70	0.84	45
c-1	535		*	Air	800	4		*			20	180	80	9.0	2.650	13	5	1.85	1.32	88
c-2	538		*	Air	800	4	*				20	180	80	9.2	2.640	15	5	0.48	0.62	88
c-3	546		*	Argon & Air	800	4		*			20	180	80	7.8	2.485	20	14	0.64+	2.46	88
c-4	547		*	" "	800	4			*		20	180	80	9.4	2.485	8	1	0.59	0.40	88
d	10	*		Vacuum	800	2				*	20	180	80	8.0	2.560	30	20	0.16	0.91	88
	11	*		"	800	2				*	40	180	80	8.4	2.560	36	22	0.18	0.76	93
	576	*		"	800	2				*	60	180	80	1.9	2.385	20	6	0.19	0.63	45
e	675	*		NO	HEAT	TREAT	MENT				60	180	80	7.7	0.690	151	16	0.06	1.020	45

\+ Oxide layer worn off before end of test.

1. Specific Wear $= \dfrac{\text{volume of wear (in}^3) \times 10^{12}}{\text{load (lb)} \times \text{sliding distance (in.)}}$

2. Coefficient of polish $= \dfrac{\text{initial journal finish } (\mu\text{in. AA}) \times \text{initial bearing finish } (\mu\text{in. AA})}{\text{final journal finish } (\mu\text{in. AA}) \times \text{final bearing finish } (\mu\text{in. AA})}$

3. Friction Index $= \dfrac{\text{friction coefficient at end of test}}{\text{friction coefficient at start of test}}$

TABLE 2: Friction and Wear Results on Untreated 304 Stainless Steel Journals Against Waukesha 88 Bearings

Test No.	Load lb	Speed rev/min	Diametral Clearance $\times 10^{-3}$ in.	Test Length $\times 10^{6}$ in.	Total Specific Wear [1]	Journal Specific Wear	Coefficient of Polish [2] (Pol)	Friction Index [3] (f_I)
595	20	180	8.4	2.575	54.8	19.0	0.02	1.240
627	20	180	8.4	2.500	98.6	25.1	0.05	2.680
637	20	180	9.1	4.480	113.9	25.4	0.07	1.980
646	20	180	8.4	2.515	63.8	30.0	0.21	2.140
655	20	180	8.2	2.590	107.2	31.2	0.05	2.000
645	40	180	8.4	1.815	123.1	18.6	0.03	2.420
783	40	180	8.3	1.950	62.7	13.5	0.08	1.080
164	60	40	3.0	3.278	25.5	12.3	0.02	2.175
674	60	40	8.3	1.500	45.0	17.6	0.04	1.645
529	60	180	6.3	2.232	33.5	7.5	0.23	0.925
577	60	180	4.0	2.580	49.5	7.5	0.01	1.300
580	60	180	1.9	2.536	44.1	4.4	0.01	1.370
581	60	180	3.1	2.541	35.6	6.2	0.03	1.420
582	60	180	7.1	2.541	64.1	6.4	0.01	1.110

1. Specific Wear $= \dfrac{\text{Volume of Wear (in}^3) \times 10^{12}}{\text{Load (lb)} \times \text{Distance (in.)}}$

2. Coefficient of Polish $= \dfrac{\text{initial journal finish } (\mu\text{in. AA}) \times \text{initial bearing finish } (\mu\text{in. AA})}{\text{final journal finish } (\mu\text{in. AA}) \times \text{final bearing finish } (\mu\text{in. AA})}$

3. Friction Index $= \dfrac{\text{friction coefficient at end of test}}{\text{friction coefficient at start of test}}$

TABLE 3: Typical Laboratory Data Sheet

LOW TEMPERATURE JOURNAL BEARING WEAR RIG

LOAD: 20 lb. TEMP: 80°F BRG I.D. 0.7580 TEST HEAD NO: 1

SPEED: 180 rev/min CLEARANCE: 0.0086 in. JOURNAL O.D: 0.7494 DATE STARTED: 20/3/68

J. FIN. 1st $\frac{18}{17,15,18}$ end 15 BRG FIN. 1st $\frac{13}{7,8,12}$ end 15 Water from north/south pH 7

04J243 - heated for 4 h at 800°C in air and then air cooled.

04J243 JOURNAL Ox. 304 SS WEIGHT	BEARING 88 B WEIGHT	WEIGHT LOSS g	RT METER min.	TIME/RUN min.	TOTAL TIME min.	INCHES TRAVELLED	FRICTION TORQUE in. lb.	COEF. OF FRICTION	COMMENTS SURFACE CONDIT'S RIDER WT.
31.3862									
	25.3514		0				2.4	0.310	
31.3853		0.0009	250	250	250	106,000	2.25	0.290	
	25.3463	0.0051	295						
31.3856		0.0006	1485	1190	1440	610,000	2.0	0.260	
	25.3373	0.0141	1542						
31.3836		0.0026	3000	1458	2898	1,230,000	1.65	0.215	
	25.3316	0.0198	3037						
31.3833		0.0029	6340	3303	6301	2,680,000	1.65	0.215	
	25.3290	0.0224							
			$SW_J =$	$\frac{2.9 \times 3.05}{8.05 \times 2.68}$	$= 0.41$				
			$SW_B =$	$\frac{22.4 \times 3.05}{9 \times 2.68}$	$= 2.82$				
			$SW_T =$	3.23					

TEST NO. 2